Great Smoky Mountains National Park Air Quality and Air Quality Related Values Research			
Park	**Title**	**Project Summary/Findings**	**Citation**
		Acidic Deposition	
Great Smoky Mountains National Park (GRSM)	Acidic deposition, ecosystem processes, and nitrogen saturation in a high elevation Southern Appalachian watershed	This was a watershed-scale monitoring study measuring precipitation, throughfall, stream hydrology, and stream chemistry conducted in the 17.4 hectare Noland Divide Watershed (1676-1920m) located in the Great Smoky Mountains National Park. The study measured cations and anions, finding nitrate the predominant anion in the streamlets. The researchers found nitrate export to be extremely high. Stream acid neutralizing capacity values are extremely low and episodic acidifications occur. Annual streamwater sulfate export was found to be 770 Eq. ha(-1)yr(-1) or about one-third of total annual inputs, indicating there is net watershed sulfate retention. The high nitrogen saturation, according to the researchers, promotes both chronic and episodic stream acidification.	Nodvin, S. C., Van Miegroet, H., Lindberg, S. E., Nicholas, N. S. & Johnson, D. W. (1995) Acidic deposition, ecosystem processes, and nitrogen saturation in a high elevation Southern Appalachian watershed. Water Air and Soil Pollution, **85**, 1647-1652.
Great Smoky Mountains National Park (GRSM)	Application of the NuCM Model to Noland Divide, White Oak Run, and Shaver Hollow for SAMI Phase I	The report follows the evaluation of SAMI and involves two phases. The first phase is to assess aquatic and forest resources response to changes in acidic deposition at Noland Divide watershed in Great Smoky Mountains National Park and White Oak Run and Shaver Hollow in Shenandoah National Park in the Southern Appalachian Mountains. The second phase (based on first phase) uses a regional approach to evaluate the response to changes in acidic deposition. The researchers used the forest Nutrient Cycling Model (NuCM) that simulates the processes that alter acid-base properties of precipitation to evaluate the watersheds.	Munson, R. K. (October 1998) Application of the NuCM Model to Noland Divide, White Oak Run, and Shaver Hollow for SAMI Phase I, Final Report. Tetro Tech, Inc, Provo, Utah.
Great Smoky Mountains National Park (GRSM)	Application of the MAGIC Model to Selected Catchments: Phase I Southern Appalachian Mountains Initiative (SAMI)	The MAGIC model (Model of Acidification of Groundwater in Catchments) was calibrated for three sites: Noland Divide in Great Smoky Mountains National Park, and White Oak Run and Shaver Hollow in Shenandoah National Park. The authors used the calibrated model to simulate the responses of stream water quality for each site to future scenarios.	Cosby, B.J. & Sullivan, T.J. (September 1998) Application of the MAGIC Model to Selected Catchments: Phase I Southern Appalachian Mountains Initiative (SAMI), Final Report.
Great Smoky Mountains National Park (GRSM)	SCALING UP TO THE LANDSCAPE: EMPIRICAL MODELING OF ATMOSPHERIC DEPOSITION IN MOUNTAINOUS LANDSCAPES: A final report to the National Park Service – PMIS #75187 Acadia and Great Smoky Mountain National Parks	The project was designed to fill a critical gap in our ability to model atmospheric deposition to heterogeneous terrains. We developed an empirical modeling approach that predicts total deposition as a function of landscape features such as elevation, vegetation type, slope and aspect. We measured indices of total deposition to the landscapes of Acadia (121 km2) and Great Smoky Mountains (2074 km2) National Parks. Area-weighted deposition was found to be 50-70% greater than NADP (wet deposition) plus CASTNet (dry deposition) monitoring station estimates. The spatially-explicit deposition estimates derived from our LANDMod are a large improvement over what is currently available. The NPS can use our LANDMod to update deposition maps to reflect changes in reference (monitoring station) deposition and/or to reflect changes in vegetation.	Weathers, K. C., S. M. Simkins, P. M. Lovett and S. E. Lindberg. 2007. SCALING UP TO THE LANDSCAPE: EMPIRICAL MODELING OF ATMOSPHERIC DEPOSITION IN MOUNTAINOUS LANDSCAPES: A final report to the National Park Service – PMIS #75187 ACAD and GRSM
Great Smoky Mountains National Park (GRSM)	Seasonal variations in aerosol composition and acidity at Shenandoah and Great Smoky Mountains National Parks	Researchers examined the concentration of elements, ions, and organic carbon monitored at Shenandoah and Great Smoky Mountains National Parks from 1988 through 1995, specifically analyzing data obtained from 1988 through 1994. The data show that significant changes in the concentrations of many aerosol constituents occur on a seasonal basis. Particulate sulfate and organic carbon concentrations are highest during the summer, while sulfur dioxide and nitrate concentrations are highest during the winter. In addition, sulfate aerosol is most acidic during summer.	Day, D. E., Malm, W. C. & Kreidenweis, S. M. (1997) Seasonal variations in aerosol composition and acidity at Shenandoah and Great Smoky Mountains National Parks. Journal of the Air & Waste Management Association, **47**, 411-418.
		Air Quality	
Great Smoky Mountains National Park (GRSM)	CLEARING THE AIR AT GREAT SMOKY MOUNTAINS NATIONAL-PARK	The study reviews the collection and analysis of National Park Service (NPS) Air Quality Division data looking at the level of pollutants and response of sensitive resources in Great Smoky Mountains National Park. The objective of the study is to describe how NPS uses scientific and regulatory information to address air pollution problems at Great Smoky Mountains National Park and also includes an assessment of the Federal Land Manager permits system.	Shaver, C.L., Tonnessen, K.A., & Maniero, T.G. (1994) CLEARING THE AIR AT GREAT SMOKY MOUNTAINS NATIONAL-PARK. Ecological Applications, **4**, 690-701.
Great Smoky Mountains National Park (GRSM)	EVALUATING THE EFFECTIVENESS OF AIR-QUALITY MANAGEMENT WITHIN THE CLASS-I AREA OF GREAT-SMOKY-MOUNTAINS-NATIONAL-PARK	This paper summarizes the forum, sponsored by the Southern Appalachian Man and the Biosphere Cooperative (SAMAB), held in March 1992 and addresses strategies to better manage air resources in the Southern Appalachians. The paper hopes to present a conceptual framework for more effective management of the Class I area of the Great Smoky Mountains National Park.	Peine, J. D., Randolph, J. C. & Presswood, J. J. (1995) EVALUATING THE EFFECTIVENESS OF AIR-QUALITY MANAGEMENT WITHIN THE CLASS-I AREA OF GREAT-SMOKY-MOUNTAINS-NATIONAL-PARK. Environmental Management, **19**, 515-526.
		Atmospheric particles/aerosols	
Great Smoky Mountains National Park (GRSM)	Aerosol light scattering measurements as a function of relative humidity: a comparison between measurements made at three different sites	Analysts examine the hygroscopic nature of ambient aerosols and the impact that aerosol growth by water uptake has on radiation transfer through the atmosphere, specifically the results of scattering coefficient measurements as a function of relative humidity at three national parks: Great Smoky Mountains, Grand Canyon, and Big Bend National Parks. The study indicates that for all three Parks, there is a considerable variability in the magnitude of the growth factor for a given RH value. When the fractions of organic carbon and soil were high, the growth factor curves were low. According to the researchers, this suggests that soil compounds and organic carbon compounds generally do not contribute as much as inorganic salts to aerosol water uptake.	Day, D. E. & Malm, W. C. (2001) Aerosol light scattering measurements as a function of relative humidity: a comparison between measurements made at three different sites. Atmospheric Environment, **35**, 5169-5176.
Great Smoky Mountains National Park (GRSM)	Characterization of fine particle sources in the Great Smoky Mountains area	The intent of the study is to characterize sources of fine particles in the Great Smoky Mountains area by analyzing ambient PM2.5 data collected at a Interagency Monitoring of Protected Visual Environments (IMPROVE) monitoring site. 1442 samples collected between March 1988 and December 2003 were analyzed for 30 elemental species using positive matrix factorization (PMF). The contributions from the carbon-rich secondary sulfate particles are likely a combination of local and regional influences. Researchers say this study would assist in the implementation plan development for attaining the air quality standards for PM2.5, regional haze rule planning, and source-specific community epidemiology.	Kim, E. & Hopke, P. K. (2006) Characterization of fine particle sources in the Great Smoky Mountains area. Science of the Total Environment, **368**, 781-794.

Great Smoky Mountains National Park (GRSM)	Characterization of ultra fine and fine particles at a site near the Great Smoky Mountains National Park	Continuous measurements of ultrafine/fine particles and gaseous species were taken for a 22-day period in the summer of 2000 at a site near the Great Smoky Mountains National Park. A varimax-rotation factor analysis was performed to explore the relationship of the fine and ultrafine particle number concentrations, gaseous species concentration, mean wind speed, and solar radiation.	Cheng, M. D. & Tanner, R. L. (2002) Characterization of ultrafine and fine particles at a site near the Great Smoky Mountains National Park. Atmospheric Environment, **36**, 5795-5806.
Great Smoky Mountains National Park (GRSM)	Comparisons of aerosol properties measured by impactors and light scattering from individual particles: refractive index, number and volume concentrations, and size distributions	The southeastern aerosol and visibility study (SEAVS), conducted at Great Smoky Mountains National Park in the summer of 1995, investigated variations in ambient aerosol size distributions and their effect on visibility. The researchers want to enhance the accuracy in the methods for measuring atmospheric aerosols, by comparing dry aerosol size distribution parameters from a MOUDI impactor and two different optical particle counters (OPCs). The results point to the need for precise OPC calibrations, particularly since these particle sizes contribute strongly to aerosol volume concentrations and to light scattering.	Hand, J. L., Kreidenweis, S. M., Kreisberg, N., Hering, S., Stolzenburg, M., Dick, W. & McMurry, P. H. (2002) Comparisons of aerosol properties measured by impactors and light scattering from individual particles: refractive index, number and volume concentrations, and size distributions. Atmospheric Environment, **36**, 1853-1861.
Great Smoky Mountains National Park (GRSM)	Development of a comprehensive, multi-scale "one-atmosphere" modeling system: application to the Southern Appalachian Mountains	In the southern Appalachian, a comprehensive three-dimensional Eulerian photochemical model (URM-IATM) was developed to simulate urban and regional gas and size-resolved aerosol concentrations of pollutants in the atmosphere, both wet and dry deposition. The modeling system was applied to simulate the evolution, transport, and removal of atmospheric pollutants over the Eastern US for a week in July 1995. Performance statistics were calculated for ozone, fine particles, and acid deposition mass fluxes. The researchers suggest URM-1ATM model can be used to assess the effects of ozone, aerosols, and wet deposition on forests, streams, visibility, and human health.	Boylan, J. W., Odman, M. T., Wilkinson, J. G., Russell, A. G., Doty, K. G., Norris, W. B. & McNider, R. T. (2002) Development of a comprehensive, multi-scale "one-atmosphere" modeling system: application to the Southern Appalachian Mountains. Atmospheric Environment, **36**, 3721-3734.
Great Smoky Mountains National Park (GRSM)	Estimates of aerosol species scattering characteristics as a function of relative humidity	In the paper, the researchers present data of the scattering characteristics of aerosols as a function of (RH) at Great Smoky Mountains National Park and at Grand Canyon National Park, comparing the two sites. The absorption of water by ambient aerosols can significantly increase the light scattering coefficient, thereby affecting visibility and climate forcing. According to the scientists, at GRSM, the measured f (RH) was on the average slightly greater than the average theoretical curve for ammonium bisulfate--implying slightly more growth than would have been predicted from the measured ammoniation; at GRCA, the curve was slightly lower.	Malm, W. C. & Day, D. E. (2001) Estimates of aerosol species scattering characteristics as a function of relative humidity. Atmospheric Environment, 35, 2845-2860.
Great Smoky Mountains National Park (GRSM)	Fine organic aerosols collected in a humid, rural location (Great Smoky Mountains, Tennessee, USA): Chemical and temporal characteristics	As part of the Southeastern Aerosol and Visibility Study (SEAVS), the study chemically characterized fine organic aerosols collected during 15 July–25 August 1995 at the Great Smoky Mountain National Park. The water-soluble organic species (WSOS) often dominated over the solvent-soluble organic species (SSOS). Organic-mass-to-organic-carbon (OM–OC) ratios are derived for WSOS, SSOS, and all identified organics, respectively, including separate OM–OC ratios for daytime and nighttime organics. The results show WSOS contributed 84% of the identified daytime fine organic aerosol mass, while the SSOS constituted 2–49%. At night-time, the SSOS dominated over WSOS.	Yu, L. E., Shulman, M. L., Kopperud, R. & Hildemann, L. M. (2005) Fine organic aerosols collected in a humid, rural location (Great Smoky Mountains, Tennessee, USA): Chemical and temporal characteristics. Atmospheric Environment, **39**, 6037-6050.
Great Smoky Mountains National Park (GRSM)	Historic PM2.5/PM10 concentrations in the southeastern United States - Potential implications of the revised particulate matter standard	The report summarizes PM2.5/PM10 particulate matter data collected with dichotomous samplers by the Tennessee Valley Authority (TVA) from 1982 to 1991. Eight monitoring stations, ranging from urban-industrial to rural-background, were operated across three east-central U.S. states. Annual average PM2.5 concentrations ranged from 12.6 to 21.3 micrograms per cubic meter (mu g/m(3)), with an overall mean of 15.7 mu g/m(3). Annual average PM10 concentrations ranged from 17.8 to 33.7 mu g/m(3), with an overall mean of 23.7 mu g/m(3). Daily PM2.5 mass appears to be associated with maximum hourly ozone from spring through fall. Sulfate compounds comprise a major portion of the measured PM2.5 particulate matter.	Parkhurst, W. J., Tanner, R. L., Weatherford, F. P., Valente, R. J. & Meagher, J. F. (1999) Historic PM2.5/PM10 concentrations in the southeastern United States - Potential implications of the revised particulate matter standard. Journal of the Air & Waste Management Association, **49**, 1060-1067.
Great Smoky Mountains National Park (GRSM)	Integrating nephelometer measurements for the airborne fine particulate matter (PM2.5) mass concentrations	The North Carolina Division of Air Quality characterized air quality in the Pamlico River airshed of eastern North Carolina. The continuous monitoring from May through October 2000 at four sites, involved collection of air samples and subsequent quantification for reactive acidic and basic gases, aerosols and fine particulate matter (PM2.5) using a 7-day Annular Denuder System (ADS). Additionally, the airborne concentration of the fine particulate matter (PM2.5) was monitored using a tapered element oscillating microbalance (TEOM).	Shendrikar, A. D. & Steinmetz, W. K. (2003) Integrating nephelometer measurements for the airborne fine particulate matter (PM2.5) mass concentrations. Atmospheric Environment, **37**, 1383-1392.
Great Smoky Mountains National Park (GRSM)	Modeling pollutant transport during high-ozone episodes in the southern Appalachian mountains	The study examined airflow patterns and pollution transport in the southern Appalachian Mountains region of the southeastern United States using mesoscale meteorological models and a Lagrangian particle dispersion model (LPDM). The objective is to identify a meteorological modeling methodology that can be used in regional modeling, and to identify ozone precursor sources that may impact the southern Appalachians. The researchers conclude there is a need for 4-dimensional models to simulate the complex topography of the Great Smoky Mountains, and also found that urban sources influence ozone concentrations within Great Smoky Mountains National Park.	Mueller, S.F., Song, A., Norris, W.B., Gupta, S., & McNider, R.T. (1996) Modeling pollutant transport during high-ozone episodes in the southern Appalachian mountains. Journal of Applied Meteorology, **35**, 2105-2120.
Great Smoky Mountains National Park (GRSM)	Moment-based simulation of microphysical properties of sulfate aerosols in the eastern United States: Model description, evaluation, and regional analysis	A six-moment microphysics module for sulfate aerosols has been incorporated in a host 3-D regional model, the Multi-scale Air Quality Simulation Platform. Model performance was examined and evaluated by comparison with in situ observations over the eastern United States for a 40-day period from July to August 1995. The model generally reproduces the spatial patterns over the eastern United States and time series variations of sulfate mass concentrations. The model successfully captured the observed size distribution, in which the sulfate is predominately located, while underestimating the nucleation and coarse modes on the basis of the size distributions retrieved from the Great Smoky Mountains.	Yu, S. C., Kasibhatla, P. S., Wright, D. L., Schwartz, S. E., McGraw, R. & Deng, A. J. (2003) Moment-based simulation of microphysical properties of sulfate aerosols in the eastern United States: Model description, evaluation, and regional analysis. Journal of Geophysical Research-Atmospheres, **108**, 26.

Deposition			
Great Smoky Mountains National Park (GRSM)	Empirical modeling of atmospheric deposition in mountainous landscapes	The researchers developed an empirical modeling approach to predict total deposition as a function of landscape features at Acadia and Great Smoky Mountains National Parks (USA). A GIS-relevant statistical nitrogen (N) and sulfur (S) deposition model (LandMod) is used to create park-wide maps of total deposition.	Weathers, K.C., Simkin, S.M., Lovett, G.M., & Lindberg, S.E. (2006) Empirical modeling of atmospheric deposition in mountainous landscapes. Ecological Applications, **16**, 1590-1607.
Cloud/Dry Deposition			
Great Smoky Mountains National Park (GRSM)	Cloud and Dry Deposition Monitoring Great Smoky Mountains National Park - Clingmans Dome, TN - 2004	Researchers calculated deposition estimates at Clingmans Dome, in Great Smoky Mountains National Park by applying the cloud water deposition computer model (CLOUD) (Lovett, 1984), parameterized with site-specific cloud water chemistry and meteorological data. Cloud water measurements show an overall decline in sulfur and nitrogen deposition over the last several years although 2004 estimates are somewhat higher than 2003 values. The estimates show that dry deposition is a minor contributor to the deposition of pollutants at high elevations. Cloud deposition is the significant pathway for deposition at these elevations.	MACTEC Engineering and Consulting, Inc. 2004. Cloud and dry deposition monitoring at Great Smoky Mountains National Park- Clingmans Dome, TN- 2004. MACTEC Engineering and Consulting, Inc., Gainesville, Florida. EPA contract number: 68-D-03-052
Great Smoky Mountains National Park (GRSM)	Estimates of cloud water deposition at mountain acid deposition program sites in the Appalachian Mountains	Cloud water deposition was estimated at three high-elevation sites, Whiteface Mountain, NY; Whitetop Mountain, VA; and Clingman's Dome, TN in the Appalachian Mountains from 1994 through 1999 as part of the Mountain Acid Deposition Program (MADPro). All sites measured seasonal cloud water deposition rates of SO4 greater than 5.0 kg/ha and NO3- rates of greater than 25 kg/ha. Thee high-elevation sites experienced additional deposition loading of SO42- and NO3- compared with lower elevation Clean Air Status and Trends Network (CASTNet) sites.	Baumgardner, R.E., Isil, S.S., Lavery, T.F., Rogers, C.M., & Mohnen, V.A. (2003) Estimates of cloud water deposition at mountain acid deposition program sites in the Appalachian Mountains. Journal of the Air & Waste Management Association, **53**, 291-308.
Nitrogen			
Great Smoky Mountains National Park (GRSM)	A comparison of techniques for measuring density and concentrations of carbon and nitrogen in coarse woody debris at different stages of decay	The study compares laboratory and field techniques to study the relationship between the stage of decay and the concentration of nitrogen (N, %) and the ratio of carbon to N (C/N) in coarse woody debris. In samples collected from the red spruce - Fraser fir (*Picea rubens - Abies fraseri*) forest in the Noland Divide watershed of Great Smoky Mountains National Park, density explained up to 60% of the variation in N and C/N in coarse woody debris. Also, statistical models relating density to N and C/N provide a means of hind casting and (or) forecasting changes in N and C/N in coarse woody debris at different stages of decay.	Creed, I. F., Webster, K. L. & Morrison, D. L. (2004) A comparison of techniques for measuring density and concentrations of carbon and nitrogen in coarse woody debris at different stages of decay. Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere, **34**, 744-753.
Great Smoky Mountains National Park (GRSM)	A conceptual model to evaluate potential watershed nitrogen saturation in the Great Smoky Mountains	A multi-year research project assessed the nitrogen saturation in a disturbed high elevation spruce-fir forest ecosystem in the Great Smoky Mountains. 3 categories of factors that control nitrogen saturation are measured including external (atmospheric) inputs, soil properties, and vegetation characteristics, contrasting from a steady-state condition. The researchers examine a conceptual model for a high-elevation watershed in Great Smoky Mountains National Park. The model will examine potential nitrogen saturation in disturbed ecosystems based on soil nitrogen levels, fluxes, and quantification of source and sink areas. The model may be useful also for ecological assessments for nitrogen critical loads	Nicholas, N.S., Van Miegroet H. and S. J. & Rose, A.K. (1998) A conceptual model to evaluate potential watershed nitrogen saturation in the Great Smoky Mountains. 91st Air and Waste Management Assessment Annual Meeting, San Diego, CA.
Ozone			
Great Smoky Mountains National Park (GRSM)	Non-methane hydrocarbons and ozone in three rural southeast United States national parks: A model sensitivity analysis and comparison to measurements	The researchers conducted a detailed modeling analysis of non-methane hydrocarbons and ozone in three southeast United States national parks, Smoky Mountains National Park (GRSM), Mammoth Cave National Park (MACA), and Shenandoah National Park (SHEN), Big Meadows for a 15-day time period in July 1995.	Kang, D. W., Aneja, V. P., Mathur, R. & Ray, J. D. (2003) Non-methane hydrocarbons and ozone in three rural southeast United States national parks: A model sensitivity analysis and comparison to measurements. Journal of Geophysical Research-Atmospheres, **108**, 17.
Soils			
Great Smoky Mountains National Park (GRSM)	Soil organic carbon content in frigid southern Appalachian Mountain soils	This study determined Soil Organic Content (SOC) in high-elevation (>1300 m) soils across northeast (N) and southwest (S) aspects and across three slope classes (7-15, 15-35, and 35-55%) per aspect in the Ridge and Valley of southwest Virginia. The author compares soils from Virginia to Great Smoky Mountains National Park from earlier research, indicating that soils on north facing slopes in both areas have higher SOC content and darker and deeper A horizons. The results reinforce the importance of using mass SOC rather than SOC concentration in regional SOC studies; demonstrating that steep northeast-facing slopes in frigid Appalachian landscapes have the highest mass SOC and highest potential for sequestering organic C in the soil.	Miller, J. O., Galbraith, J. M. & Daniels, W. L. (2004) Soil organic carbon content in frigid southern Appalachian Mountain soils. Soil Science Society of America Journal, **68**, 194-203.
Stream Chemistry			
Great Smoky Mountains National Park (GRSM)	Acid-base chemistry of high-elevation streams in the great smoky mountains	Longitudinal and temporal variations in water chemistry were measured in low-order, high-elevation streams in the Great Smoky Mountains, primarily to evaluate the processes responsible for the acid-base chemistry. The results indicate that the streams ranged in average base flow ANC from –30 to 28 mgreq L–1 and pH of 4.54 to 6.40.	Cook, R.B., Elwood, J.W., Turner, R.R., Bogle, M.A., Mulholland, P.J., & Palumbo, A.V. (1994) ACID-BASE CHEMISTRY OF HIGH-ELEVATION STREAMS IN THE GREAT SMOKY MOUNTAINS. Water Air and Soil Pollution, **72**, 331-356.
Great Smoky Mountains National Park (GRSM)	Concentration-Duration-Frequency Curves for pH in a Stream in the Great Smoky Mountains	Monitors were installed at four sites in a stream in the Great Smoky Mountains National Park recording multiple parameters. The data were analyzed, and durations for excursions below each pH level were assigned probability quantiles and plotted, creating a concentration-duration-frequency curve. The curve potentially allows comparisons with toxicity data, as well as, temporal and spatial comparisons.	Robinson, R.B. & Roby, J.C. (2006) Concentration-duration-frequency curves for pH in a stream in the Great Smoky Mountains. Journal of Environmental Engineering-Asce, **132**, 1600-1605.

Great Smoky Mountains National Park (GRSM)	Denitrification potential in sediments of headwater streams in the southern Appalachian Mountains, USA	The researchers investigated patterns of seasonal variability and the role of resource availability on denitrification potential in the sediments of headwater streams in the southern Appalachian Mountains. Stream water and sediments were sampled seasonally in 2 streams of contrasting NO3-N availability, Noland Creek (high NO3-N) and Walker Branch (low NO3-N) in the Great Smoky Mountains National Park. Denitrification potential was greater in Noland Creek than in Walker Branch. A question in the study is if additional loss of NO3-N might be negatively affecting ecosystem production in streams with low concentrations of NO3-N, or where N is limiting to algae and microbes. The researchers suggest that NO3-N availability is the primary factor limiting potential denitrification in Southern Appalachian streams.	Martin, L. A., Mulholland, P. J., Webster, J. R. & Valett, H. M. (2001) Denitrification potential in sediments of headwater streams in the southern Appalachian Mountains, USA. Journal of the North American Benthological Society, **20**, 505-519.
Great Smoky Mountains National Park (GRSM)	Factors affecting streamwater chemistry in the Great Smoky Mountains, USA	Results from extensive surveys conducted in October 1993 and March 1994 at Great Smoky Mountains National Park showed that stream pH values were near or below 5.5, and Acid Neutralizing Capacity (ANC) was below 50 mu eq L(-1) at high elevations. Researchers in this study classified each catchment into one of five water quality districts based upon within-basin elevational gradients of streamwater quality. Atmospheric deposition is an important factor affecting water quality at high elevations. Nitrate was the dominant strong acid anion in streamwater in many catchments. Continued high atmospheric loadings of N will likely spread N saturation of catchments downslope into areas where second growth forests are now maturing, according to the researchers.	Flum, T. & Nodvin, S. C. (1995) Factors affecting streamwater chemistry in the Great Smoky Mountains, USA. Water Air and Soil Pollution, **85**, 1707-1712.
Great Smoky Mountains National Park (GRSM)	Parametric modeling of water quality and sampling strategy in a high-altitude Appalachian stream	Multiple linear regression models were developed using water quality data from a high-altitude stream in the Noland Divide Watershed of Great Smoky Mountains National Park. Independent variables, including stream pH and flow rate, were used in the models to predict concentrations and loads for acid neutralizing capacity (ANC), chloride, hydrogen ion, nitrate, potassium, sodium, and sulfate; also to evaluate time trends and determine whether acidification is worsening. Statistically significant declines occurred in nitrate, ANC loads and concentrations with time, but not in hydrogen ion or sulfate concentrations. The stream concentrations and loads of nitrate decrease over time was thought to be associated with a net vegetative uptake of incoming nitrogen by understory growth. ANC is the capacity of solutes plus particulates to neutralize acid in the stream system; if this is low, the streams are less able to buffer against low pH which can lead to larger drops in storm events. The decline in ANC is due to worsening acidification and might cause declines in aquatic organisms.	Robinson, R. B., Wood, M. S., Smoot, J. L. & Moore, S. E. (2004) Parametric modeling of water quality and sampling strategy in a high-altitude Appalachian stream. Journal of Hydrology, **287**, 62-73.
Great Smoky Mountains National Park (GRSM)	Storm Event Monitoring in the Great Smoky Mountains National Park	Baseline stream water pH was monitored in the Great Smoky Mountains National Park using multi-parameter water quality loggers and auto-samplers installed along a stream reach in the Great Smoky Mountains National Park. The researchers suspected poor water quality in storm events to be partly to blame for extirpation of native brook trout. For example, metals analyses of storm event samples showed increases in some trace toxic metals (Al, Cu, and Zn) during storm events and exceedances of water quality criteria.	R. B. Robinson, C. Roby, J. Buchanan, T. Barnett, and Moore S.E. (2005) Storm Event Monitoring in the Great Smoky Mountains National Park, EWRI 2005: Impacts of Global Climate Change. World Water Congress 2005. Impacts of Global Climate Change; Raymond Walton - Editor, May 15–19, 2005, Anchorage, Alaska, USA.
Sulfur			
Great Smoky Mountains National Park (GRSM)	An analysis of the yearly changes in sulfur concentrations at various national parks in the United States, 1980-1996	The researchers indicate that data markings of increasing trends in summer concentrations of particulate sulfur at Shenandoah and at Great Smoky Mountains National Parks may be an analytical artifact resulting from the switch from the Stacked Filter Units (SFU) measurement system to the IMPROVE (Interagency Monitoring of Protected Visual Environments) measurement system that occurred during the winter of 1987. After investigating seasonal averages of sulfur concentrations for successive pairs of years for the period 1980-1996 for about 70 national park sites in the United States from the two databases, the researchers could not find a difference in the methods used.	Patterson, P., Iyer, H., Sisler, J. & Malm, W. C. (2000) An analysis of the yearly changes in sulfur concentrations at various national parks in the United States, 1980-1996. Journal of the Air & Waste Management Association, **50**, 790-801.
Great Smoky Mountains National Park (GRSM)	Elevational trends in the fluxes of sulfur and nitrogen in throughfall in the southern Appalachian mountains: Some surprising results	From 1986-1989, scientists measured atmospheric concentrations and fluxes in precipitation and throughfall, and additionally model dry and cloudwater deposition in a spruce-fir forest of the Great Smoky Mountains National Park. They used multiple samplers to measure hydrologic fluxes in rain and throughfall events beneath spruce forests above (1940 m) and below (1720 m) the cloud base. The fluxes of most ions showed a 10-50% increase with elevation due to the similar to 70 cm yr(-1) cloudwater input at 1920 m. However, total inorganic nitrogen exhibited a 40% lower flux in throughfall at 1920 m than at 1740 m. The scientists suggest higher dry deposition to trees at 1740 m and higher canopy uptake of nitrogen by trees at 1920 m.	Shubzda, J., Lindberg, S. E., Garten, C. T. & Nodvin, S. C. (1995) Elevational trends in the fluxes of sulfur and nitrogen in throughfall in the southern Appalachian mountains: Some surprising results. Water Air and Soil Pollution, **85**, 2265-2270.
Visibility/Haze			
Great Smoky Mountains National Park (GRSM)	Application of a color-appearance model to vision through atmospheric haze	Researchers conducted a field study at Great Smoky Mountains National Park to quantify the relationship of haze to the color appearance of objects being viewed. Color appearance of objects was quantified by color matching with a special visual colorimeter. The Hunt94 color-appearance model was used to compare these matches with simultaneous spectral measurements. The researchers suggest the results challenge the manner in which current air quality-visibility models are being utilized.	Mahadev, S. & Henry, R. C. (1999) Application of a color-appearance model to vision through atmospheric haze. Color Research and Application, **24**, 112-120.
Air Quality Effects to Sensitive Resources:			
Park	**Title**	**Project Summary/Findings**	**Citation**
Aquatic Resources			
Great Smoky Mountains National Park (GRSM)	Effects of Acidic Deposition on Aquatic Resources in the Southern Appalachians with a Special Focus on Class I Wilderness Areas	The purpose of the report is to address the concerns of air pollution on the Southern Appalachians, including acidic deposition and its effects on surface waters. The report summarizes the existing knowledge and evaluates and makes recommendations concerning acidic deposition, this includes new methodologies to address the current or future problems.	Herlihy, A.T., Kaufmann P.R., Stoddard, J.L., Esheleman, K.N. & Bulger, A.J. (August, 1996) Effects of Acidic Deposition on Aquatic Resources in the Southern Appalachians with a Special Focus on Class I Wilderness Areas. Prepared for the Southern Appalachian Mountains Initiative.

Great Smoky Mountains National Park (GRSM)	THE EFFECTS OF STREAM ACIDITY ON BENTHIC INVERTEBRATE COMMUNITIES IN THE SOUTH-EASTERN UNITED-STATES	Investigators determined patterns in invertebrate community structure from analysis of benthic samples taken quarterly for 1 year from four sites in the Great Smoky Mountains National Park. Sites ranged in baseflow pH from 4.5 to 6.8, with a corresponding range in inorganic monomeric aluminum concentrations from 3 to 197-mu-g l-1. The results indicate that direct effects of pH and Al (affecting survival) were more important than indirect effects of food availability in determining changes in invertebrate community structure between the study sites.	Rosemond, A. D., Reice, S. R., Elwood, J. W. & Mulholland, P. J. (1992) THE EFFECTS OF STREAM ACIDITY ON BENTHIC INVERTEBRATE COMMUNITIES IN THE SOUTH-EASTERN UNITED-STATES. Freshwater Biology, **27**, 193-209.
Mercury and Airborne Toxics			
Great Smoky Mountains National Park (GRSM)	Historical Mercury Trends in Tree Rings	Investigators gathered tree core material from a select tree species near the current mercury monitoring sites at Elkmont, Clingman's Dome, and Look Rock to study for historical trends of mercury. Chemical data gathered from the tree-rings will allow us to investigate the trend of mercury uptake overtime to better access how current mercury deposition has changed. A variety of species were collected: red spruce, hemlock, fraser fir, red oak, bitternut hickory, and tulip poplar. Researchers found mean concentrations were statistically different and tree cores from the Look Rock site represented the highest mean concentration of GSMNP sites. Hg concentrations were greatest in the soils of Clingmans Dome; this area receives the most rainfall of the sites and the soil is lower in pH (typical of spruce-fir ecosystem). Clingmans Dome soils are also typically higher in organic matter. Overall, between tree concentrations had much more variance than within tree - suggesting site and soil influences.	Investigator: Suzanne Fisher, Tennessee Valley Authority, Investigator Annual Report (IAR) 34122, 30279
Ozone Effects			
Great Smoky Mountains National Park (GRSM)	Ambient Ozone Effects on Plants Along An Elevational Gradient in the Great Smokies	The aim of the proposed research is to record, map and explain spatial patterns in ozone symptoms in plant taxa growing along elevational gradients. This will be used as the basis for developing a regional assessment and map of potential ozone impacts on natural vegetation in the southeastern United States.	Investigator: Dr Howard Neufeld, IAR 24044, 25336
Great Smoky Mountains National Park (GRSM)	Anatomical and morphological determinants of ozone injury in sensitive and insensitive genotypes of native wildflowers in Great Smoky Mountains National Park	According to recent models, there are three main parameters that affect the sensitivity of native plants to ozone: 1) stomatal conductance, which determines the amount of ozone that enters a leaf, 2) detoxification, which is the biochemical anti-oxidant capacity of a leaf to de-toxify ozone and the reactive oxygen species it generates, and 3) internal leaf anatomy and morphology, which determines the diffusion pathway of ozone and other reactive oxygen species. Some studies have shown that species with greater internal airspaces, or more internal cell surface area, as well as thinner leaves, are more susceptible to ozone. In our studies of native wildflowers, we have evidence that there exist sensitive and insensitive genotypes within native wildflower populations. The purpose of this study is to determine if any of those differences in sensitivity can be attributed to either anatomical or morphological variation in leaf structure between these genotypes.	Investigator: Dr Howard Neufeld, IAR 31491
Great Smoky Mountains National Park (GRSM)	CHARACTERIZATION OF AMBIENT OZONE LEVELS IN THE GREAT-SMOKY-MOUNTAINS-NATIONAL-PARK	Ambient ozone data collected at two sites in the Great Smoky Mountains National Park (GSMNP) are summarized and compared with data from an urban and a low-elevation rural site. The ozone climatology in the park is found to be similar to that of other remote sites in the southern Appalachian Mountain region. Terrain elevation is identified as a major factor influencing local ozone levels. Episodes of high ozone concentrations (greater-than-or-equal-to 90 ppb) in the park are attributable to the ozone transport into the park.	Mueller, S. F. (1994) CHARACTERIZATION OF AMBIENT OZONE LEVELS IN THE GREAT-SMOKY-MOUNTAINS-NATIONAL-PARK. Journal of Applied Meteorology, **33**, 465-472.
Great Smoky Mountains National Park (GRSM)	CLOUDWATER AND OZONE EFFECTS UPON HIGH-ELEVATION RED SPRUCE - A SUMMARY OF STUDY RESULTS FROM WHITETOP MOUNTAIN, VIRGINIA	The article integrates the results of a number of studies on the effects of cloudwater and ozone (O-3) on red spruce (*Picea rubens*) seedlings, saplings, and mature trees at Whitetop Mountain, VA, over a 3-yr period. Seedlings and mature branches in the various treatments were compared with respect to growth rates, gas exchange rates, foliar nutrition, and chlorophyll and wax content. Soil solution, throughfall, and foliar responses of mature trees at low cloud and high cloud sites were also monitored.	Thornton, F.C., Joslin, J.D., Pier, P.A., Neufeld, H., Seiler, J.R., & Hutcherson, J.D. (1994) CLOUDWATER AND OZONE EFFECTS UPON HIGH-ELEVATION RED SPRUCE - A SUMMARY OF STUDY RESULTS FROM WHITETOP MOUNTAIN, VIRGINIA. Journal of Environmental Quality, **23**, 1158-1167.
Great Smoky Mountains National Park (GRSM)	Effects of drought and shade on the response to ozone by cutleaf coneflower (Rudbeckia laciniata var. digitata) in Great Smoky Mountains National Park	We want to conduct controlled studies on the influence of drought and shade on the responses of this species to ozone, using small plots in which we modify soil moisture conditions and light. At Purchase Knob, two main plots (sunny, at forest edge) and shady (interior of forest above ozone monitoring station) were set up. Within each plot, 5 subplots were established, each with 3 treatments, consisting of 1 m2 plots subjected to either no treatment (control), excess watering (2X ambient) or droughted (tarps over plots to exclude rain). A survey of 20 sensitive and 20 insensitive plants growing along the forest edge showed that sensitive plants produced significantly fewer flowers, and fewer seeds per plant than insensitive plants. This suggests that ozone might be impairing the reproductive output of the sensitive plants.	Investigator: Dr Howard Neufeld, IAR 31492
Great Smoky Mountains National Park (GRSM)	Effects of Ozone on Forest Trees in the Southern Appalachians: An Assessment of the Current State of Knowledge	The report's primary objectives are to summarize the existing state of knowledge on the effects of ozone on forest trees and to evaluate the use of available assessment methodologies for predicting future changes in ozone effects to forest trees in the SAMI region. The report presents findings on visible injury, growth and physiological factors, and the exposure-response.	Chappelka, A.H., Samuelson, L.J., Skelly, J.M., & Lefohn A.S. (October, 1996) Effects of Ozone on Forest Trees in the Southern Appalachians: An Assessment of the Current State of Knowledge. Prepared for SAMI.
Great Smoky Mountains National Park (GRSM)	Empirical evidence of growth decline related to visible ozone injury	Differences in radial growth at breast height of yellow-poplar (*Liriodendron tulipifera*) and black cherry (*Prunus serotina*) were tested between individual trees with a history of visible foliar ozone injury and those not expressing foliar ozone injury at three sites in Great Smoky Mountains National Park, USA. No significant differences in growth for black cherry were found, although there was a 12% reduction in radial growth over 5 yrs and 8% over 10 yrs. There was a significant difference in radial growth for yellow-poplar of 43% over 5 yrs and 30% over 10 yrs. The researchers ruled out other possible variables in the reduction in radial growth.	Somers, G. L., Chappelka, A. H., Rosseau, P. & Renfro, J. R. (1998) Empirical evidence of growth decline related to visible ozone injury. Forest Ecology and Management, **104**, 129-137.

Great Smoky Mountains National Park (GRSM)	Evaluation of ozone injury on foliage of black cherry (*Prunus serotina*) and tall milkweed (*Asclepias exaltata*) in Great Smoky Mountains National Park	The objective of the survey is to determine the incidence and severity of visible foliar symptoms of ambient ozone injury on sensitive plant species, particularly on black cherry (*Prunus serotina*) seedlings and saplings and tall milkweed (*Asclepias exaltata*) plants in Great Smoky Mountains National Park (GRSM). The study was conducted by trail surveys during late summer 1992. Symptoms of ozone injury were observed on both black cherry seedlings and saplings, with about 47% of the black cherry having ozone injury; results showing significantly more injury to the leaves and plant of black cherry in the NW section of the Park. Tall milkweed was evaluated twice for ozone injury with the percent injured plants, 74 and 79% for the first and second survey, respectively. The regression analyses showed no relationships in ozone injury with respect to aspect, slope or elevation. The researchers indicate that ozone injury to sensitive plant species is widespread throughout GRSM.	Chappelka, A., Renfro, J., Somers, G. & Nash, B. (1997) Evaluation of ozone injury on foliage of black cherry (*Prunus serotina*) and tall milkweed (*Asclepias exaltata*) in Great Smoky Mountains National Park. Environmental Pollution, **95**, 13-18.
Great Smoky Mountains National Park (GRSM)	Interactive effects of ozone and climate on tree growth and water use in a southern Appalachian forest in the USA	Researchers examined hourly to seasonal patterns of stem growth and sap flow velocity in mature trees at three forested sites, Look Rock, Twin Creeks, and Oak Ridge, in eastern Tennessee near the Great Smoky Mountains. The objective was to evaluate the effects of variations in ambient ozone exposure and climate on patterns of stem growth and water use. Ambient ozone caused a periodic slowdown in seasonal growth patterns that was attributable in part to amplification of diurnal patterns of water loss in tree stems. Results showed statistically significant increases in ozone-induced daily sap flow and led to seasonal losses in stem growth of 30-50% for most species in a high ozone year.	McLaughlin, S. B., Nosal, M., Wullschleger, S. D. & Sun, G. (2007) Interactive effects of ozone and climate on tree growth and water use in a southern Appalachian forest in the USA. New Phytologist, 174, 109-124.
Great Smoky Mountains National Park (GRSM)	Interactive effects of ozone and climate on water use, soil moisture content and streamflow in a southern Appalachian forest in the USA	The objectives of this study were to define possible interactions among background ozone levels, climate, and forest water use, which involved initial studies at a whole-tree level at three forested watersheds at Look Rock, TN close to the Great Smoky Mountains. The study involved analysis of change at a watershed scale using monthly flow rates across annual time steps. Results showed that daily water loss and recovery cycles in the trees were amplified with increased ozone exposure. The researchers found statistically significant increases in whole-tree canopy conductance, depletion of soil moisture in the rooting zone, and reduced late-season streamflow in forested watersheds resulting from increasing ambient ozone levels. Higher ozone levels might also exacerbate drought and climate changes.	McLaughlin, S. B., Wullschleger, S. D., Sun, G. & Nosal, M. (2007) Interactive effects of ozone and climate on water use, soil moisture content and streamflow in a southern Appalachian forest in the USA. New Phytologist, 174, 125-136.
Great Smoky Mountains National Park (GRSM)	Interpreting spatial variation in ozone symptoms shown by cutleaf cone flower, *Rudbeckia laciniata* L.	Researchers recorded visible injury, genetic variation, ozone concentrations, stomatal conduction and light in populations of cutleaf coneflower (Rudbeckia laciniata) at Purchase Knob and Clingmans Dome in Great Smoky Mountains National Park (USA). The researchers found some coneflower populations consist of very few genets whereas others are genetically very diverse, which was said to complicate interpretation of injury scores, and also raise the question if the species is a good bioindicator species. Also, the measurements of ozone, stomatal conductance and light gradients within plant canopies showed that variation in symptom expression in cutleaf coneflower is primarily due to variation in light, rather than ozone flux.	Davison, A. W., Neufeld, H. S., Chappelka, A. H., Wolff, K. & Finkelstein, P. L. (2003) Interpreting spatial variation in ozone symptoms shown by cutleaf cone flower, *Rudbeckia laciniata* L. Environmental Pollution, **125**, 61-70.
Great Smoky Mountains National Park (GRSM)	Mature black cherry used as a bioindicator of ozone injury	Researchers reported 3-year results relating ambient ozone concentrations to visible foliar injury for mature black cherry (*Prunus serotina*) in Great Smoky Mountains National Park (GRSM) and Shenandoah National Park (SHEN) for the summers of 1991-1993. Plots were established at different elevations adjacent to ozone monitoring stations--at Cove Mountain, Look Rock and Twin Creeks in GRSM, and at Dickey Ridge, Big Meadows and Sawmill Run in SHEN. Researchers found incidence in 1991 to be 60% for GRSM and 45% for SHEN. In 1992 and 1993, incidence was very similar in both parks, with approximately 33% of the trees affected. There was increasing ozone injury to black cherry at higher elevations; the high elevation sites also exhibited the highest ozone concentrations. The researchers state that the presence of ozone induced symptoms on black cherry at both parks during these three years show that the species is sensitive to ambient ozone exposures common to the region.	Chappelka, A., Skelly, J., Somers, G., Renfro, J. & Hildebrand, E. (1999) Mature black cherry used as a bioindicator of ozone injury. Water Air and Soil Pollution, 116, 261-266.
Great Smoky Mountains National Park (GRSM)	Ozone and PM2.5 exposure and acute pulmonary health effects: A study of hikers in the Great Smoky Mountains National Park	Replicating a study at Mt. Washington, New Hampshire (USA), the researchers conducted an observational study of adult day hikers of the Charlies Bunion trail for two sampling periods, fall 2002 and summer 2003 in Great Smoky Mountains National Park. Ozone and PM2.5 concentrations measured during the study were below the current federal standards, and there were no significant associations of acute changes in pulmonary function with either pollutant.	Girardot, S. P., Ryan, P. B., Smith, S. M., Davis, W. T., Hamilton, C. B., Obenour, R. A., Renfro, J. R., Tromatore, K. A. & Reed, G. D. (2006) Ozone and PM2.5 exposure and acute pulmonary health effects: A study of hikers in the Great Smoky Mountains National Park. Environmental Health Perspectives, **114**, 1044-1052.
Great Smoky Mountains National Park (GRSM)	Ozone injury on cutleaf coneflower (*Rudbeckia laciniata*) and crown-beard (*Verbesina occidentalis*) in Great Smoky Mountains National Park	Surveys were conducted to determine the magnitude of visible foliar ozone injury symptoms, including incidence and severity, on cutleaf coneflower (*Rudbeckia laciniata*) and crown-beard (*Verbesina occidentalis*) in Great Smoky Mountains National Park during the summers of 2000 and 2001. Surveys were conducted at three locations: Clingmans Dome, Cherokee Orchard Road and Purchase Knob. The species are found throughout GRSM and are sensitive to ozone. Plants were sampled both on and off-trail, recording the number of injured and uninjured leaves and plants. Cutleaf coneflower had more foliar symptoms due to ambient concentrations of ozone than crown-beard for the 2-year study. Researchers found severity of injury was greatest for cutleaf coneflower near the edge of the trail, possibly due to light conditions. Ozone injury was greatest on the lower leaves for both species, with over 95% of the injured leaves occurring on the lower 50% of the plant.	Chappelka, A. H., Neufeld, H. S., Davison, A. W., Somers, G. L. & Renfro, J. R. (2003) Ozone injury on cutleaf coneflower (*Rudbeckia laciniata*) and crown-beard (*Verbesina occidentalis*) in Great Smoky Mountains National Park. Environmental Pollution, **125**, 53-59.
Great Smoky Mountains National Park (GRSM)	Ozone Pollution Damage to Growth and Physiology of Native Trees and Wildflowers in GRSM	The purpose of this project was to obtain a greater understanding of the impacts of ozone pollution on selected tree and wildflower species in Great Smoky Mountains National Park (GRSM). The study involved tree ring analyses to relate tree growth to past ozone concentration and climate variations, study of the effects of ozone on mature tree growth and water use, determination of the relationship between ambient ozone concentrations and growth and reproduction of native wildflowers in GRSM, and public education related to ozone bioindicator species. Researchers found no consistent patterns in radial growth patterns and no significant changes in growth over time related to ozone pollution. There was significant growth reduction of mature forest trees during high ozone years and increases in water use. The researchers suggest that the loss in soil water may have an effect on late-season streamflow.	Chappelka, A., H. Neufeld, S. McLaughlin, S. Sachs and J. Renfro. 2006. Ozone Pollution Damage to Growth and Physiology of Native Trees and Wildflowers in Great Smoky Mountains National Park. National Park Service. NPS # D-609 PMIS # 6 ; IAR 31644, 25554

Great Smoky Mountains National Park (GRSM)	Ozone uptake in *Prunus serotina* , *Acer rubrum* and *Quercus rubra* forest trees of different sizes	Researchers measured photosynthesis, stomatal conductance, foliar nutrients, and ozone uptake in mature black cherry (*Prunus serotina*), northern red oak (*Quercus rubra*) and red maple (*Acer rubrum*) trees during the 1994 and 1995 growing seasons in the Great Smoky Mountains National Park. The objective was to characterize ozone uptake in forest trees and provide a scaling of leaf physiological rates. Ambient ozone conditions and physiological characteristics were measured in understorey seedlings and saplings, and the upper crown of mature canopy trees at two research sites, Twin Creeks and Cove Mountain in GRSM. Seasonal ozone dose to northern red oak and red maple in the upper crown was approximately double that of understory seedlings and saplings. Seasonal ozone dose to black cherry was up to six times greater in mature trees than in seedlings and saplings.	Samuelson, L. J. & Kelly, J. M. (1997) Ozone uptake in *Prunus serotina* , *Acer rubrum* and *Quercus rubra* forest trees of different sizes. New Phytologist, **136**, 255-264.
Great Smoky Mountains National Park (GRSM)	Seasonal development of ozone-induced foliar injury on tall milkweed (*Asclepias exaltata*) in Great Smoky Mountains National Park	The goals of the study was to develop ozone exposure relationships for leaf cohorts and individual tall milkweeds (*Asclepias exaltata*) at Mt. Sterling Gap (1525m) in Great Smoky Mountains National Park in 2000 and 2001. The investigators looked at leaves from the beginning to the end of the season to ensure accurate estimation of ozone induced foliar injury. Plants were classified as ozone-sensitive or insensitive based on the amount of foliar injury. Ozone-induced foliar injury was observed earlier in the season, and increased more rapidly for these ozone-sensitive individuals. Most leaves abscised without prior ozone-like stippling or chlorosis. Failure to take this into account can result in under-estimation of the effects of ozone on these plants. Ozone caused significant amounts of foliar injury on tall milkweed plants, and was most severe on older, lower leaves. Researchers found about 75% of tall milkweed individuals sensitive to ozone, having 25% injury on symptomatic leaves.	Souza, L., Neufeld, H. S., Chappelka, A. H., Burkey, K. O. & Davison, A. W. (2006) Seasonal development of ozone-induced foliar injury on tall milkweed (*Asclepias exaltata*) in Great Smoky Mountains National Park. Environmental Pollution, **141**, 175-183.
Great Smoky Mountains National Park (GRSM)	Seasonal profiles of leaf ascorbic acid content and redox state in ozone-sensitive wildflowers	Researchers analyzed leaf ascorbic acid (AA) and dehydroascorbic acid (DHA) in the sensitive wildflower species cutleaf coneflower (*Rudbeckia laciniata*), crown-beard (*Verbesina occidentalis*), and tall milkweed (*Asclepias exaltata*) at Great Smoky Mountains National Park during the summer of 2001. The study's intent was to assess the role of ascorbate in protecting the plants from ozone stress and to assess seasonal patterns of ascorbate pool size and redox status in leaves, in order to determine possible relationships with ozone-induced foliar injury. . Wildflowers were randomly selected from natural stands in GRSM. Tall milkweed was surveyed at Mt. Sterling Gap; cutleaf coneflower at Clingmans Dome, and crown-beard near the Twin Creeks Natural Resource Center. Tall milkweed contained greater quantities of AA than crown-beard or cutleaf coneflower. DHA was elevated in crown-beard and cutleaf coneflower compared to tall milkweed.	Burkey, K. O., Neufeld, H. S., Souza, L., Chappelka, A. H. & Davison, A. W. (2006) Seasonal profiles of leaf ascorbic acid content and redox state in ozone-sensitive wildflowers. Environmental Pollution, **143**, 427-434.
Great Smoky Mountains National Park (GRSM)	Seedling insensitivity to ozone for three conifer species native to Great Smoky Mountains National Park	Exposure of conifers to air pollution and higher ozone doses is an ecological concern in eastern parks, particularly, Great Smoky Mountains National Park (GRSM), because of the potential growth impairment of these plants. Seedlings of three species of conifers, Table Mountain pine (*Pinus pungens*), Virginia pine (*Pinus virginiana*), and eastern hemlock (*Tsuga canadensis*), were exposed to various levels of ozone in open-top chambers for one to three seasons (1998-1992) in Great Smoky Mountains National Park in Tennessee, USA. Researchers used a combination of episodic profiles (1988) and modified ambient exposure regimes (1989-92). Results show for all three species, there was no statistically significant responses to ozone in terms of total biomass accumulation, height or diameter growth for the three consecutive years. A table is given showing exposure periods and indices. The conifer species are insensitive to ambient and elevated levels of ozone in GRSM, which is most likely due to the slow growing nature of the species and the low stomatal conductance.	Neufeld, H. S., Lee, E. H., Renfro, J. R. & Hacker, W. D. (2000) Seedling insensitivity to ozone for three conifer species native to Great Smoky Mountains National Park. Environmental Pollution, **108**, 141-151.
Great Smoky Mountains National Park (GRSM)	SENSITIVITY OF SEEDLINGS OF BLACK-CHERRY (*PRUNUS-SEROTINA* EHRH) TO OZONE IN GREAT-SMOKY-MOUNTAINS-NATIONAL-PARK .1. EXPOSURE-RESPONSE CURVES FOR BIOMASS	Researchers analyzed the response of seedlings of black cherry (*Prunus serotina*) to ozone at 1989 and 1992 using the open-top chamber exposure facility at Uplands Eield Research Laboratory in Great Smoky Mountains National Park during the growing seasons of 1989 and 1992. The objective was to develop exposure-response curves for black cherry seedlings exposed to ozone in open-top chambers, the first of its kind. Methods include collecting open-pollinated seed, growing for a season, and exposing the seedlings to different ozone treatments. The models showed that leaf and root biomass are the most sensitive to ozone, whereas stem biomass is less sensitive. Also, 1992 seedlings showed greater sensitivity to ozone than did the 1989 seedlings.	Neufeld, H. S., Lee, E. H., Renfro, J. R., Hacker, W. D. & Yu, B. H. (1995) SENSITIVITY OF SEEDLINGS OF BLACK-CHERRY (*PRUNUS-SEROTINA* EHRH) TO OZONE IN GREAT-SMOKY-MOUNTAINS-NATIONAL-PARK .1. EXPOSURE-RESPONSE CURVES FOR BIOMASS. New Phytologist, **130**, 447-459.
Great Smoky Mountains National Park (GRSM)	Stomatal behavior of ozone-sensitive and -insensitive coneflowers (*Rudbeckia laciniata var. digitata*) in Great Smoky Mountains National Park	The objective of the study was to understand physiological mechanisms that might be at play in varying ozone sensitivity in cutleaf coneflower (*Rudbeckia laciniata var. digitata*) individuals at Great Smoky Mountains National Park. Researchers hypothesized that the stomatal response to varying environmental conditions might be the cause of varying sensitivity levels. Research was conducted at the forests edge at Purchase Knob in mid-summer of 2004. The cutleaf coneflowers were given a sensitivity score, followed by measurements of stomatal densities and gas exchange responses to light and vapor on the leaves of the plant. Results showed stomata of sensitive plants were less responsive than those of insensitive plants to experimentally increased and decreased light intensities. According to the researchers, different physiological attributes vary independently within an individual plant, and these can collectively confer sensitivity or insensitivity to O-3 injury.	Grulke, N. E., Neufeld, H. S., Davison, A. W., Roberts, M. & Chappelka, A. H. (2007) Stomatal behavior of ozone-sensitive and -insensitive coneflowers (*Rudbeckia laciniata var. digitata*) in Great Smoky Mountains National Park. New Phytologist, **173**, 100-109.
Great Smoky Mountains National Park (GRSM)	Sub-canopy deposition of ozone in a stand of cutleaf coneflower	The ozone exposure of a plant is expressed in terms of the concentration above the canopy or as a time-weighted index. According to the researchers, in order to understand the physiological effects of ozone, it is necessary to quantify the ozone flux to individual leaves as they develop. This requires knowing the deposition velocity and concentration of the pollutant as a function of height throughout the plant canopy. The researchers used a high-order closure model of subcanopy turbulence to estimate ozone profiles in two stands of cutleaf coneflower (*Rudbeckia laciniata*) located at the Purchase Knob at Great Smoky Mountains National Park, USA.	Finkelstein, P. L., Davison, A. W., Neufeld, H. S., Meyers, T. P. & Chappelka, A. H. (2004) Sub-canopy deposition of ozone in a stand of cutleaf coneflower. Environmental Pollution, **131**, 295-303.

Great Smoky Mountains National Park (GRSM)	RED SPRUCE RESPONSE TO OZONE AND CLOUDWATER AFTER 3 YEARS EXPOSURE	This study reports on the results of a 3-yr study conducted at a high elevation site in the southern Appalachians to determine if cloudwater and ozone (O3) adversely affect the growth of red spruce seedlings (Picea rubens Sarg.). Field chambers were established at Whitetop Mountain, VA (elevation 1689 m), in 1988. Three replicate chamber treatments were constructed to produce the following treatments: exclusion of clouds and O3, ambient O3, with clouds removed, and exposure to both clouds and O3. Researchers analyzed potted native seedlings and seedlings grown from seed collected in the Great Smoky Mountains National Park. Results showed that no differences in seedling diameter growth were found for either seedling type. Increased nutrient leaching of needle Ca and Mg was observed in cloudwater treatments.	Thornton, F. C., Pier, P. A. & McDuffie, C. (1992) RED SPRUCE RESPONSE TO OZONE AND CLOUDWATER AFTER 3 YEARS EXPOSURE. Journal of Environmental Quality, **21**, 196-202.
Great Smoky Mountains National Park (GRSM)	Relationships between anatomical characteristics and ozone sensitivity of leaves of several herbaceous dicotyledonous plant species at Great Smoky Mountains National Park	The study's objective was to examine if correlations exist between ozone sensitivity and the above leaf characteristics of plants at the Upland Research facility at Great Smoky Mountains National Park. Researchers hypothesized that an increase in stomatal density (number of stomata per unit area of leaf surface) is related to an increase in ozone sensitivity in leaves. The methods consisted of microscopic study of cellular injury levels in plants and correlation with existing ozone sensitivity values. The three ozone sensitive species, *Sassafras albidum* , *Rudbeckia lacimata* , and *Rubus canadensis* had higher stomatal densities and more intercellular spaces among palisade cells compared with less sensitive species (*Magnolia tripetela* , *Aster divaricatus* , and *Liquidamber styraciflua*). Researchers found that ozone sensitivity is associated with leaf characteristics that relate to the ability of ozone to diffuse into leaves, and the ability of ozone to diffuse among the target cells.	Evans, L. S., Albury, K. & Jennings, N. (1996) Relationships between anatomical characteristics and ozone sensitivity of leaves of several herbaceous dicotyledonous plant species at Great Smoky Mountains National Park. Environmental and Experimental Botany, **36**, 413-420.
Great Smoky Mountains National Park (GRSM)	Relationships between cellular injury, visible injury of leaves, and ozone exposure levels for several dicotyledonous plant species at Great Smoky Mountains National Park	The purpose of this research was to relate ozone stress and the amount of visible foliar injury due to ozone using native broadleaf plants at Great Smoky Mountains National Park in 1989 and 1990. Results showed a statistically significant relationships between dead parenchyma cells and the percentage of leaf area with necrosis or stippling for *Sassafras albidum* , *Rudbeckia lacinata* and *Rubus canadensis* . The number of dead palisade parenchyma cells was also significantly correlated with cumulative ozone exposure of foliage for S. albidum and R. canadensis. The investigators point out that the results show that *S. albidum* , *R. lacinata* and *R. canadensis* are good ozone indicator species.	Evans, L. S., Adamski, J. H. & Renfro, J. R. (1996) Relationships between cellular injury, visible injury of leaves, and ozone exposure levels for several dicotyledonous plant species at Great Smoky Mountains National Park. Environmental and Experimental Botany, **36**, 229-237.
Great Smoky Mountains National Park (GRSM)	The effects of ozone on a lower slope forest of the Great Smoky Mountain National Park: Simulations linking an individual tree model to a stand model	In this study, researchers use a tree physiology model, TREGRO, and a stand succession model, ZELIG to estimate the possible future ozone effects on a forest located in the Twin Creeks region in Great Smoky Mountains National Park. The study investigated yellow-poplar (Liriodendron tulipifera), red maple (Acer rubrum), and black cherry (Prunus serotina) since these species have been shown in experiments to have depressed photosynthetic rates as a result of ozone. The researchers were interested in the long-term effects of ozone on the species abundance and forest basal area--using TREGRO to examine changes in ozone photosynthetic rate, extrapolating from seedling to mature tree, and Zelig to estimate any reduction in the supply of carbon and the effect on competition between individual trees. Results showed that current ambient levels of ozone measured at mid-elevations were predicted to reduce the abundance of yellow-poplar by 10% over the next 100 years. An increase of ozone of 50% above current levels was predicted to decrease yellow-poplar abundance by 30%.	Weinstein, D. A., Gollands, B. & Retzlaff, W. A. (2001) The effects of ozone on a lower slope forest of the Great Smoky Mountain National Park: Simulations linking an individual tree model to a stand model. Forest Science, **47**, 29-42.
Great Smoky Mountains National Park (GRSM)	Visible ozone injury on forest trees in Great Smoky Mountains National Park, USA	Researchers estimated visible foliar ozone for mature black cherry, sassafras and yellow-poplar in Great Smoky Mountains National Park during the summer of 1991 at the Cove Mountain, Look Rock and Twin Creek sites, ranging in elevation from 597-1265 m. Ozone exposure/plant response relationships were also examined. Branches from trees at each plot were evaluated for the incidence and severity of ozone injury, also using ANOVA (regression analysis) to find statistical relationships. Researchers found all species at the three locations exhibiting visible ozone injury, but significantly greater percentage of ozone injury to the leaf area and injured leaves for black cherry and sassafras at Cove Mountain where ozone concentrations was highest. There was no statistical significance in ozone exposure/tree response relationships for any of the species.	Chappelka, A., Somers, G. & Renfro, J. (1999) Visible ozone injury on forest trees in Great Smoky Mountains National Park, USA. Water Air and Soil Pollution, **116**, 255-260.
Pollutants			
Great Smoky Mountains National Park (GRSM)	Determination of Calcium, Magnesium, and Aluminum in Red Spruce (Picea rubens) and Fraser Fir (Abies fraseri) Foliage and Surrounding Soil in the Southern and Middle Appalachians	The Red Spruce has also shown a milder decline attributed to acid deposition. Acid deposition (SO42- and NO3-) leaches important nutrients from soils. It is the increase in mobility of the nutrients calcium and magnesium and the toxic aluminum, that has been adversely affecting the red spruce. By determining Ca, Mg, and Al in soils and foliage, a characterization of acid deposition can be achieved. Sample sites include Balsam High Top, Clingman's Dome, Double Spring Gap, Mt. LeConte, Mt. Sterling, and Spruce Mountain in the Great Smoky Mountains National Park (NC, TN), and Richland Balsam on the Blue Ridge Parkway (NC). Foliar samples were collected from 30 red spruce at each site. The results show little significant evidence suggesting that regional sulfur dioxide and oxides of nitrogen emissions affect the health of the red spruce.	Investigator: David Butcher, Western Carolina University, IAR 37568
Great Smoky Mountains National Park (GRSM)	Estimated ultraviolet radiation doses in wetlands in six national parks	Ultraviolet-B radiation doses were estimated for 1024 wetlands in six national parks: Acadia, Glacier, Great Smoky Mountains, Olympic, Rocky Mountain, and Sequoia/Kings Canyon National Parks. The mean dose across all wetlands and parks was 19.3 W-h m(-2) (range of 3.4-32.1 W-h m(-2)). Dissolved organic carbon (DOC), a key determinant of water-column UV-B flux, ranged from 0.6 (analytical detection limit) to 36.7 mg C L-1 over all wetlands and parks. According to the researchers, the regional differences in UV-B wetland dose illustrate the importance of considering all aspects of exposure in evaluating the potential impact of UV-B on aquatic organisms.	Diamond, S. A., Trenham, P. C., Adams, M. J., Hossack, B. R., Knapp, R. A., Stark, S. L., Bradford, D., Corn, P. S., Czarnowski, K., Brooks, P. D., Fagre, D., Breen, B., Detenbeck, N. E. & Tonnessen, K. (2005) Estimated ultraviolet radiation doses in wetlands in six national parks. Ecosystems, **8**, 462-477.

Great Smoky Mountains National Park (GRSM)	Exploring interactions between pollutant emissions and climatic variability in growth of red spruce in the Great Smoky Mountains National Park	Scientists use dendrochronological studies to investigate the status of red spruce (*Picea ruben*) along elevational extremes in Great Smoky Mountains National Park, particularly if climate and pollution have an effect on radial growth of these trees. The methods include tree core analysis of stands of virgin red spruce/Fraser fir forests and developing a time series of radial growth since 1950. This includes assessment of climate and precipitation during the last half century, as well as, environmental stressors such as pests and emissions of pollutants. Researchers use regression analysis to study relationships between environmental factors and radial growth. Results show red spruce was in a decline from the 1940s to the mid-1970s, and then a recovery in the decline due to new regulations on sulfur dioxide emissions. For trees near ridges, the changes in radial growth was due combination of climatic conditions and annual emissions of nitric oxides and sulfur dioxide. The researchers identified a red spruce growth signal related to pollution throughout the southern Appalachians.	Webster, K.L., Creed, I.F., Nicholas, N.S., & Van Miegroet, H. (2004) Exploring interactions between pollutant emissions and climatic variability in growth of red spruce in the Great Smoky Mountains National Park. Water Air and Soil Pollution, **159**, 225-248.
Great Smoky Mountains National Park (GRSM)	Heavy metal concentrations in northern water snakes (*Nerodia sipedon*) from East Fork Poplar Creek and the Little River, East Tennessee, USA	Scientists compared metal levels in tissues of northern water snakes (Nerodia sipedon) collected from the upper reach of East Fork Poplar Creek (EFPC) in the United States Department of Energy's National Security Complex with concentrations in tissues of northern water snakes from a reference reach of the Little River downstream from the Great Smoky Mountains National Park (GRSM). The primary objective was to determine if northern water snakes were suitable bioindicators of metal contamination. Results showed levels of arsenic, chromium, lead, manganese, mercury, and selenium were significantly higher in the blood, kidney, liver, muscle, and skin of EFPC northern water snakes compared with tissues of snakes from the reference site in GRSM. In addition, even though female water snakes were larger than male snakes, there was no significant increase in metal concentration in the tissues of females, possibly due to the maternal transfer of metals to eggs, according to the researchers.	Campbell, K. R., Campbell, T. S. & Burger, J. (2005) Heavy metal concentrations in northern water snakes (Nerodia sipedon) from East Fork Poplar Creek and the Little River, East Tennessee, USA. Archives of Environmental Contamination and Toxicology, **49**, 239-248.
Great Smoky Mountains National Park (GRSM)	Nonmethane hydrocarbons in the rural southeast United States national parks	Measurements of volatile organic compounds (VOCs) were made at three rural sites in national parks in the southeast U.S. Researchers analyzed nonmethane hydrocarbon in Mammoth Cave, Great Smoky Mountains, and Shenandoah National Parks from June through September, from 1995-1997. The results show that anthropogenic VOCs from automobile exhaust appeared to be dominant at Mammoth Cave National Park, Cove Mountain at Great Smoky Mountains National Park; other sources were also apparent at Big Meadows in Shenandoah National Park. VOCs varied both in concentration and order depending on park and year, but the dominant VOCs for all three sites were isoprene (6.3 to 18.4 ppbv), propane (2.1 to 12.9 ppbv), isopentane (1.3 to 5.7 ppbv), and toluene (1.0 to 7.2 ppbv).	Kang, D. W., Aneja, V. P., Zika, R. G., Farmer, C. & Ray, J. D. (2001) Nonmethane hydrocarbons in the rural southeast United States national parks. Journal of Geophysical Research-Atmospheres, 106, 3133-3155.
Sulfur and Nitrogen			
Great Smoky Mountains National Park (GRSM)	Factors affecting streamwater chemistry in the Great Smoky Mountains, USA	The study consisted of extensive surveys measuring pH, Acid Neutralizing Capacity (ANC), and atmospheric deposition, particularly nitrate (N) in the Great Smoky Mountains in October 1993 and March 1994. Results showed nitrate was the dominant anion in streamwater in many catchments. Most high elevation catchments appear to be N saturated. Continued high atmospheric loadings of nitrate will likely spread nitrate saturation of catchments downslope into areas where second growth forests are now maturing.	Flum, T. & Nodvin, S.C. (1995) Factors affecting streamwater chemistry in the Great Smoky Mountains, USA. Water Air and Soil Pollution, **85**, 1707-1712.
Great Smoky Mountains National Park (GRSM)	Is coarse woody debris a net sink or source of nitrogen in the red spruce - Fraser fir forest of the southern Appalachians, USA?	Researchers examined a the role of carbon woody debris (CWD) on nitrogen saturation in a red spruce (Picea rubens) - Fraser fir (Abies fraseri) forest in the Noland Divide watershed, located in Great Smoky Mountains National Park in the summers of 1998 and 1998. The forest is in advanced stages of nitrogen saturation, due to high inputs of nitrogen by dry and cloud deposition. The objective of the study was to find out if CWD is a net source or sink of nitrogen in the system. Researchers collected coarse woody debris (CWD) in GRSM, using N content in standing live trees and snags as a reference point-- to see if CWD may have an effect on the nitrogen (N) export signal in streams, and if the sequence of decay of CWD would reveal nitrogen dynamics within the system. Results indicated CWD as a net source of N in early stages of decay, and a net store or sink of N in later stages of decay.	Creed, I. F., Morrison, D. L. & Nicholas, N. S. (2004) Is coarse woody debris a net sink or source of nitrogen in the red spruce - Fraser fir forest of the southern Appalachians, USA? Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere, **34**, 716-727.
Great Smoky Mountains National Park (GRSM)	Is there synchronicity in N input and output fluxes at the Noland Divide Watershed, a small N-saturated forested catchment in the Southern Appalachians?	The study examines the magnitude and timing of nitrogen fluxes into, through, and out of a small, first-order catchment in the Great Smoky Mountains National Park. In particular, the researchers look at how climatic conditions affect interannual variations in the N output signal in high-elevation red spruce (*Picea rubens*)-Fraser fir (*Abies fraseri*) forests.	Tarboton, D.G.; Webster, K.L.; Shubzda, J.; Robinson, B.; Smoot, J.; Johnson, D.W.; Lindberg, S.E.; Lovett, G.; Nodvin, S.; Moore, S. (2001) Is There Synchronicity in Nitrogen Input and Output Fluxes at the Noland Divide Watershed, a Small N-Saturated Forested Catchment in the Great Smoky Mountains National Park? The Scientific World, **1**, 480-492.
Great Smoky Mountains National Park (GRSM)	Nitrogen and phosphorus concentrations in forest streams of the United States	This project analyzed patterns in water chemistry for over 300 streams in small, forested watersheds across the United States. Concentrations of dissolved organic N (mean 0.32 mg N/L) were similar to those of NO3-, whereas ammonium (NH4+) concentrations were much lower (mean 0.05 mg N/L). Nitrate dominated the N loads of streams draining hardwood forests, whereas dissolved organic N dominated the streams in coniferous forests. Concentrations of inorganic phosphate were typically much lower (mean 12 mg P/L) than dissolved organic phosphate (mean 84 mg P/L).	Binkley, D., Son, Y. & Valentine, D. W. (2000) Do forests receive occult inputs of nitrogen? Ecosystems, **3**, 321-331.
Great Smoky Mountains National Park (GRSM)	Nitrogen saturation and soil N availability in a high-elevation spruce and fir forest	The study investigated high-elevation (1524-2000 m) spruce (*Picea rubens*) and Fraser fir (*Abies fraseri*) forests of the Great Smoky Mountains National Park (GRSM) during the summer of 1995. Indicators of soil N availability (total soil N concentrations, extractable NH4-N, extractable NO3-N, and C/N ratios) were measured in soil Oa and A horizons in 33 study plots. The researchers indicate that soil N availability and NO3-N leaching in high-elevation spruce and fir forests of GRSM will increase in response to regional warming.	Garten, C.T. (2000) Nitrogen saturation and soil N availability in a high-elevation spruce and fir forest. Water Air and Soil Pollution, **120**, 295-313.

Great Smoky Mountains National Park (GRSM)	Relationships between soil nitrogen dynamics and natural N abundance in plant foliage from Great Smoky Mountains National Park	To test the hypothesis that naturally occurring nitrogen (N) isotope ratios in foliage are an indicator of soil N dynamics in forests, the researchers established replicate plots at 8 locations ranging in elevation (615-1670m) and nitrogen poor and rich sites in the Great Smoky Mountains National Park. Soil and organic layers were sampled to determine N levels.	Garten, C. T. & Van Miegroet, H. (1994) Relationships between soil nitrogen dynamics and natural N abundance in plant foliage from Great Smoky Mountains National Park. Can. J. For. Res. **24**, 1636-1645.
Great Smoky Mountains National Park (GRSM)	SEASONAL-VARIATION IN NITRATE REDUCTASE-ACTIVITY IN NEEDLES OF HIGH-ELEVATION RED SPRUCE TREES	The research objective was to assess seasonal and site variation in foliar nitrate reductase activity and its utility as a biochemical marker for the uptake of nitrogen oxide pollutants in high-elevation forests. Scientists measured nitrate reductase activity in current-year needles of red spruce (*Picea rubens*) saplings at two high-elevation stands (1935 and 1720 m) in the Great Smoky Mountains for two growing seasons between September 1987 and September 1988. Comparing deposition of nitric acid vapor at a nearby site to nitrate reductase activity, researchers find needle nitrate reductase activity is not an unequivocal marker for foliar uptake of nitrogen oxides during air pollutant episodes. The results show that red spruce are capable of assimilating nitrate in foliage, and this is variable throughout the year.	Tjoelker, M. G., McLaughlin, S. B., Dicosty, R. J., Lindberg, S. E. & Norby, R. J. (1992) SEASONAL-VARIATION IN NITRATE REDUCTASE-ACTIVITY IN NEEDLES OF HIGH-ELEVATION RED SPRUCE TREES. Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere, **22**, 375-380.
Great Smoky Mountains National Park (GRSM)	Simulated Effects of Reduced Sulfur, Nitrogen, and Base Cation Deposition on Soils and Solutions in Southern Appalachian Forests	The researchers explored the effects of reduced N, S and base cations on two contrasting forest ecosystems, acidic red spruce (*Picea ruben)* site and a moderately acidic mixed deciduous site in the southern Appalachians using the Nutrient Cycling Model (NuCM). The primary purpose of the study was to examine how the two sites respond to reduced deposition.	Johnson, D.W., Susfalk, R.B., Brewer, P.F., & Swank, W.T. Simulated Effects of Reduced Sulfur, Nitrogen, and Base Cation Deposition on Soils and Solutions in Southern Appalachian Forests. Journal of Environmental Quality, **28**, 1336-1346.
Great Smoky Mountains National Park (GRSM)	Simulated responses of red spruce forest soils to reduced sulfur and nitrogen deposition	The study explored the implications of reducing S and N deposition on red spruce forests of the southern Appalachians using the Nutrient Cycling Model (NuCM).	Johnson, D.W., Susfalk, R.B., & Brewer, P.F. (1996) Simulated responses of red spruce forest soils to reduced sulfur and nitrogen deposition. Journal of Environmental Quality, **25**, 1300-1309.
Great Smoky Mountains National Park (GRSM)	Vegetation, biomass, and nitrogen pools in a spruce-fir forest of the Great Smoky Mountains National Park	The landscape-scale investigation concentrates on N dynamics in an unlogged 17.4 ha watershed of *Picea rubens-Abies fraseri* forests of the Great Smoky Mountains. Biomass of living and dead trees was measured, as was nitrogen content of the water in the study area. According to the researchers, the forests appear to be saturated with nitrogen.	Pauley, E.F., Nodvin, S.C., Nicholas, N.S., Rose, A.K., & Coffey, T.B. (1996) Vegetation, biomass, and nitrogen pools in a spruce-fir forest of the Great Smoky Mountains National Park. Bulletin of the Torrey Botanical Club, **123**, 318-329.
Great Smoky Mountains National Park (GRSM)	Variation in overstory nitrogen uptake in a small, high-elevation southern Appalachian spruce-fir watershed	The objective was to determine spatial variability in tree nitrogen (N) uptake in a small high-elevation catchment in the Great Smoky Mountains National Park, and to assess the influence of stand and landscape properties on N uptake. Researchers estimate tree N uptake for fifty 20 × 20 m plots in the Noland Divide Watershed (NDW), considering components such as stem growth, foliage increment, and mortality. The study focuses on measurements of mortality of spruce, fir, and yellow birch (Betula alleghaniensis) from 1993 and 1998 stand inventories; throughfall N flux measured in summers 1998 and 1999; litterfall N return; tissue N analyses; and atmospheric N deposition and root turnover estimates from the literature. On average, spruce accounted for 60% of the total N increment, while fir and birch each accounted for about 20% of the increment. Total litterfall was, on average, 40% needles, 20% deciduous foliage, and 40% twigs, bark, and reproductive tissues. N uptake is correlated with measures of stand structure, but not with elevation or aspect.	Barker, M., Van Miegroet, H., Nicholas, N. S. & Creed, I. F. (2002) Variation in overstory nitrogen uptake in a small, high-elevation southern Appalachian spruce-fir watershed. Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere, **32**, 1741-1752.
Great Smoky Mountains National Park (GRSM)	Watershed scale variability of nitrogen dynamics and related biogeochemical research at Noland Divide Watershed and associated spruce-fir sites	Measurement at the Noland Divide Watershed (NDW) has shown that there is a clear decoupling between atmospheric N input and streamwater export, and that climate and hydrology play an important role in translating external (deposition) and internal (mineralization) N sources into a stream export signal. The study design was expanded outside the NDW to examine soil N and C dynamics across 8 plots located between 1525 m and 1980m elevation on similar aspects and having similar stand structure (live basal area: 40-60 m-2 ha-1). Preliminary analysis of the N mineralization data for 2001 indicate that: (1) there is significant N mineralization release in fall also (10-60 kg ha-1), similar to summer rates (15-35 kg ha-1); (2) most of the N is nitrified; (3) N mineralization rates are comparable to earlier NDW values; (4) more inorganic N leached out of the incubation core in fall; (5) N mineralization rates differ among plots but do not follow a consistent pattern with elevation.	Investigator: Dr Niki Nicholas, IAR 24996